The Role of Ceramics and Ceramic Matrix Composites in NASA's Advanced Space Propulsion Programs

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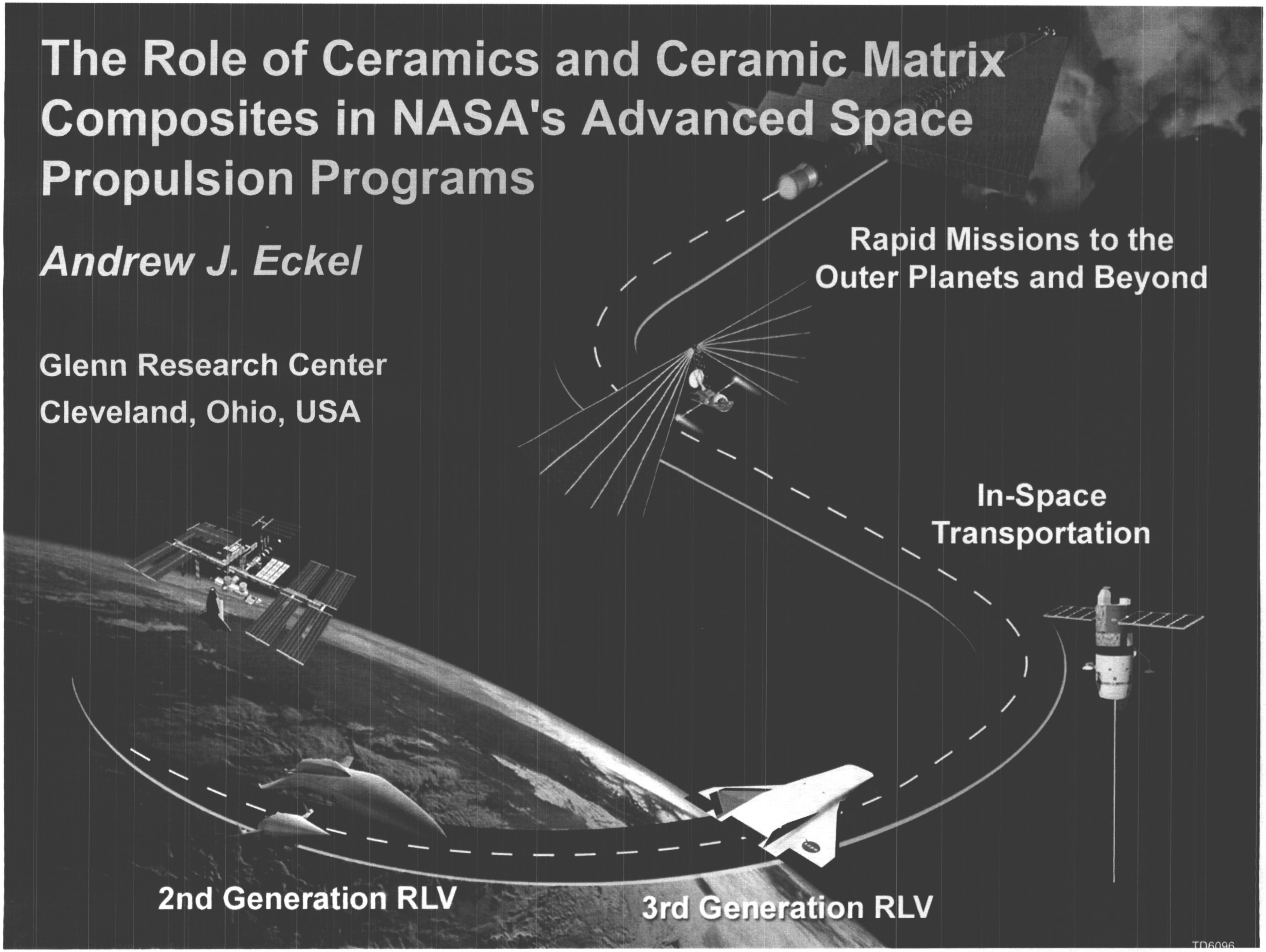


Observations

- After an extended period of inactivity, NASA is entering a new era of space exploration and exploitation. This has presented the materials community with new opportunities to insert advanced materials into operational space propulsion systems.

- There has been a fundamental shift in the approach to managing, designing and carrying out space missions. This has led to a change in the approach to developing and utilizing technology.

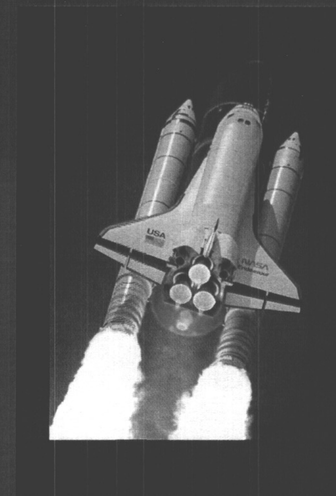
- Key to inserting advanced materials into space propulsion systems is a cross-discipline approach in which materials are engineered into existing, evolving, and revolutionary vehicles and missions planned for the near and foreseeable future.

Outline

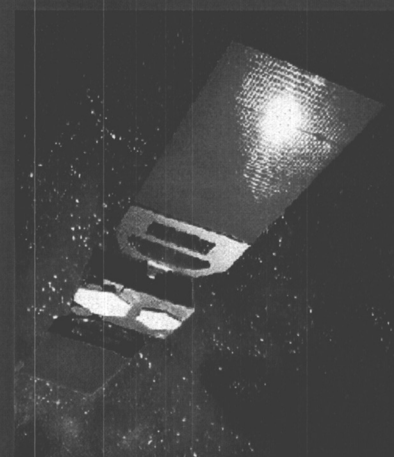
- **Why the increased interest in Space Transportation?**
- **What is the current structure of NASA's Space Transportation Program?**
- **Why are ceramic composites of interest?**
- **What specific propulsion technologies and components are being targeted for development?**
- **Where are the key technical shortfalls that are preventing more widespread application of ceramic matrix composites?**

Why the Increased Interest in Space?

- The Space Shuttle fleet is aging and is expensive to operate.

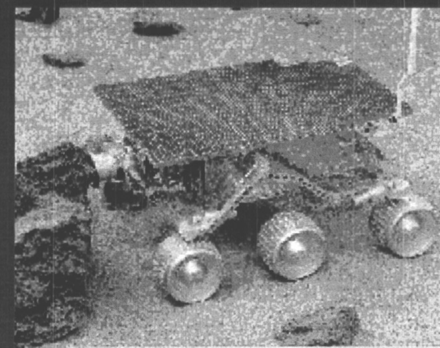


- The quantity of space science missions is increasing.



Shift in Programmatic Approach?

- Missions are more technically focused, have shorter planning/design cycles and have smaller budgets than previous efforts.
  - e.g., Mars Pathfinder, Lunar Prospector and Stardust, Commercial Satellites

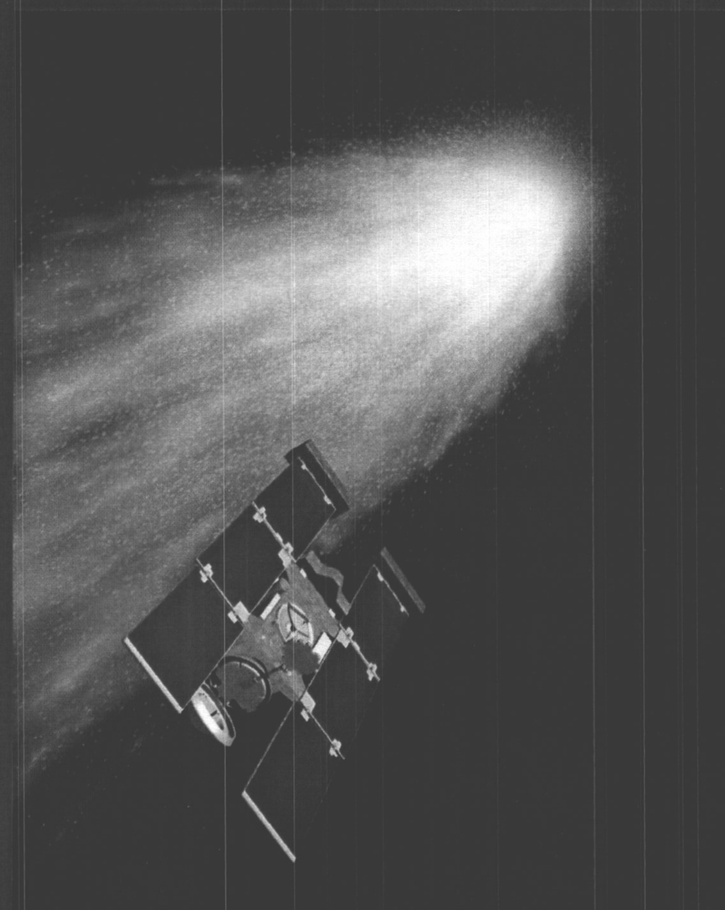


- Missions are high risk ventures that demand utilization of advanced technology, but cannot afford time and budget required for materials development.

STARDUST Spacecraft Mission

Launched Feb 6, 1999
Encounter comet WILD2, January 2004
Earth Return January 2006

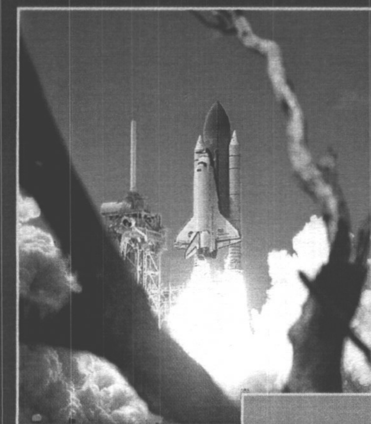
Primary mission objective:
Collect and return over 100 particles in the 0.1 micron to 1 micron size range to earth.
Cost: ~$200M

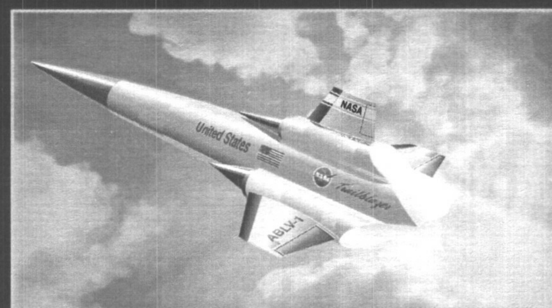


Advanced materials key to mission's success

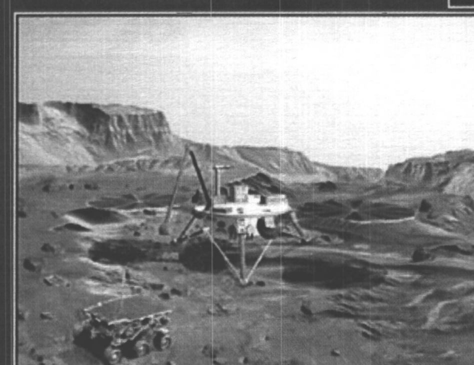
Propulsion Systems

Earth-to-Orbit
- Expendable Launch Vehicles
- Reusable Launch Vehicles

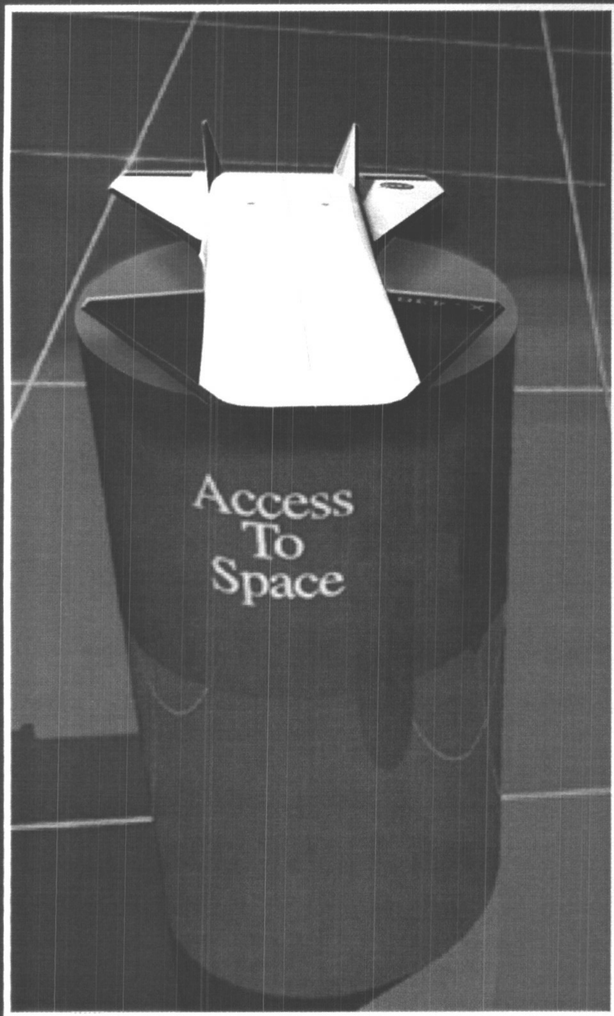




In-Space Transportation
- Satellite Insertion
- Planetary Missions/Sample Return
- Positioning
- Stationkeeping
  (Satellite/RLV/Space Station)



Enterprise Goals



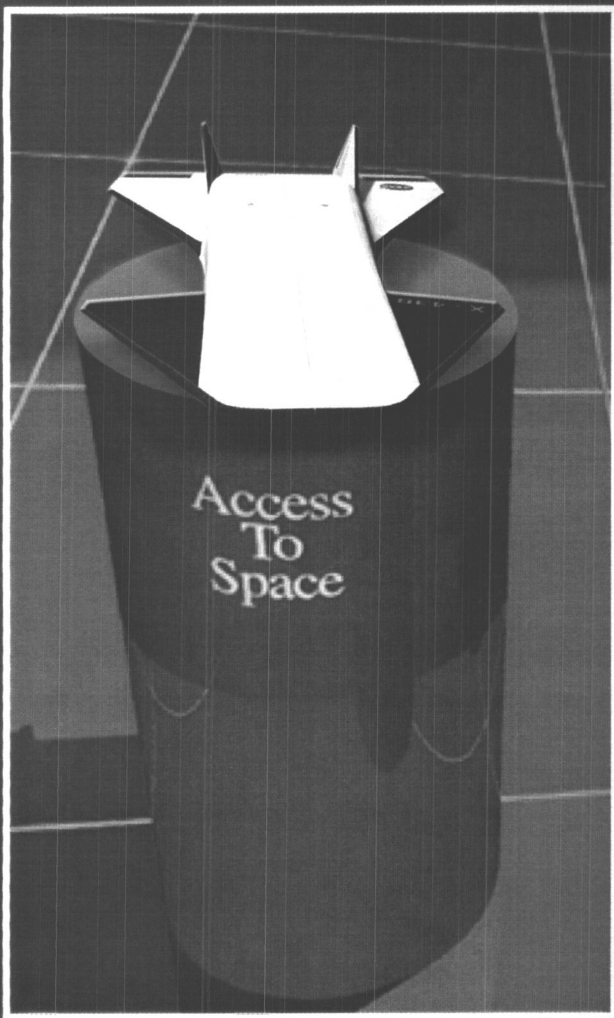
GOALS: Earth-to-Orbit

- Within 10 years,
  - Increase the safety by two orders of magnitude
  - Reduce the cost to NASA transportation of placing payloads in orbit by one order of magnitude.
- Within 25 years,
  - Increase the safety by four orders of magnitude.
  - Reduce the cost of placing payloads in orbit by two orders of magnitude.

GOALS: In-Space Transportation (As related to Office of Space Science missions)

- Enable mission not currently feasible with current propulsion
- Reduce missions trip time to the outer planets and beyond
- Increase payload mass, volume, and electrical power available to the payload
- Increase safety and reliability

Enterprise Goals



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2nd Gen
SLI

3nd Gen
Hypersonics

GOALS: In-Space Transportation
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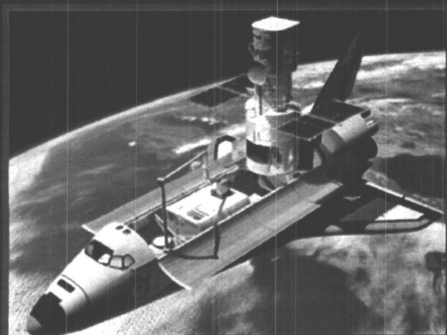
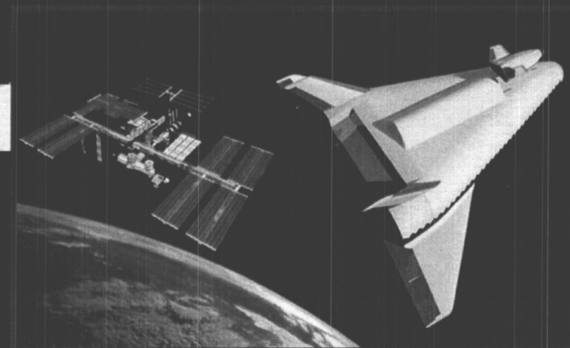
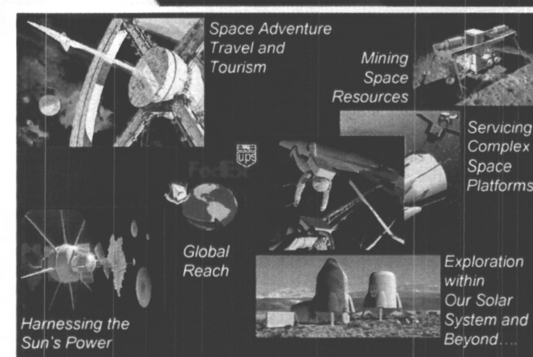
Generations of Reusable Launch Vehicles



Today: Space Shuttle
1st Generation RLV



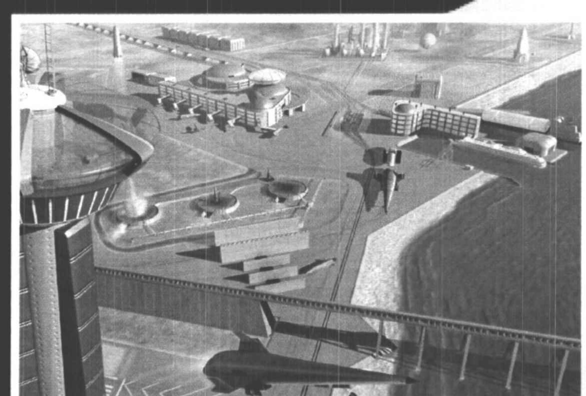
2010: 2nd Generation RLV (SLI)
- **10x Cheaper**
- **100x Safer**



Opening New Space Markets Will Require Ultra Low Cost Transportation at Airline Levels of Safety

2025: 3rd Generation RLV
- **100x Cheaper**
- **10,000x Safer**

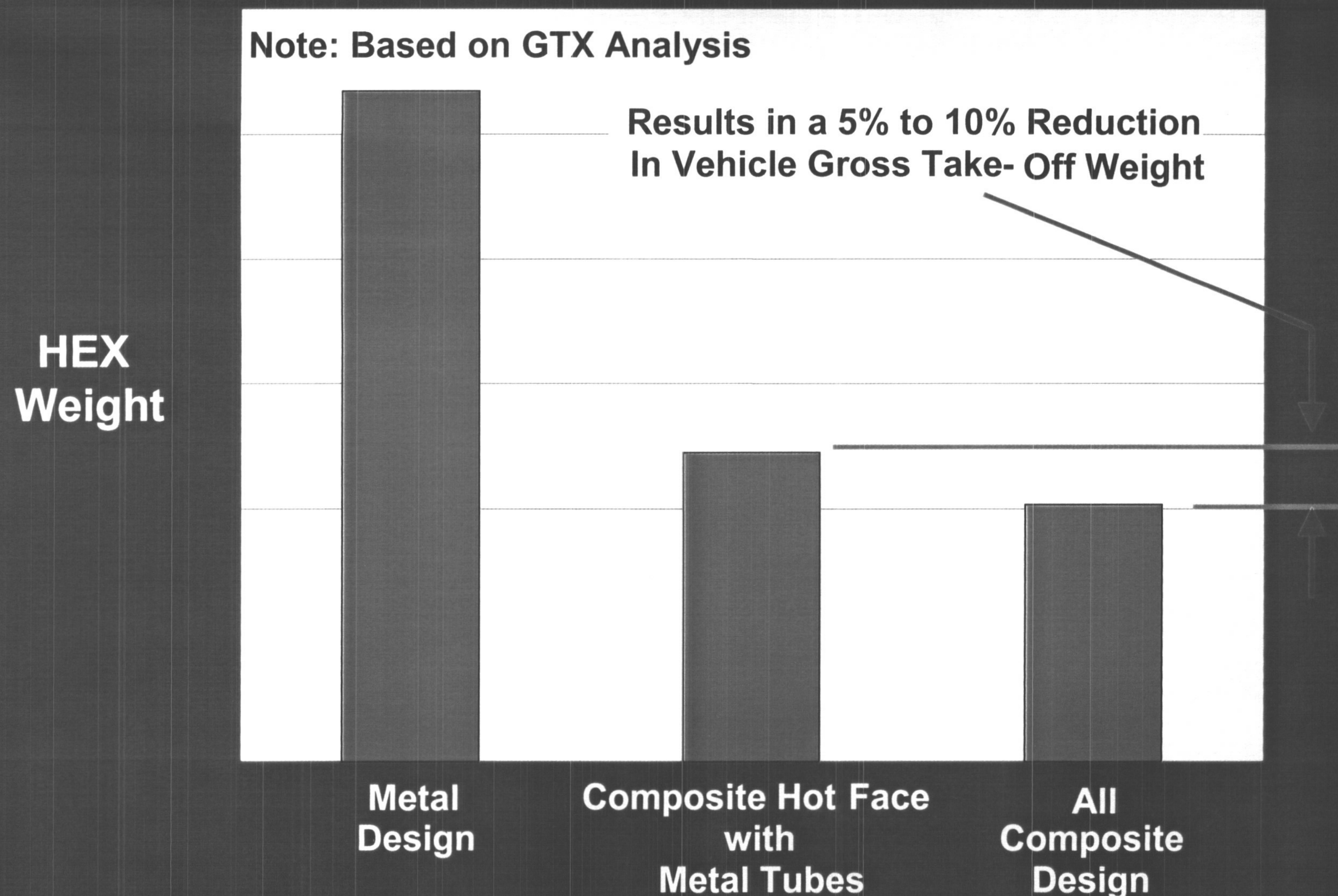
2040: 4th Generation RLV
- **Routine Passenger Space Travel**
- **Safe and Affordable for the average citizen and commerce**



Key Drivers for Utilizing Ceramic and Composite Materials

- Weight: Lighter weight than metallic designs
  - High Thrust-to-Weight for Launch Vehicles
  - Lower Propulsion System Mass for Satellite and Planetary Missions
- Enabling: High Temperature Capability and/or Oxidation Resistance Enabling for Many Propulsion Concepts
- Performance: Increased operational margin -- translates to enhanced range, life and/or system payload (e.g., E-T-O propulsion systems, satellites, deep space probes)
- Simplicity: Higher temperature capability may reduce or eliminate coolant system requirements (e.g., on re-entry)
- Cost: Reduced System Operational Costs (e.g., less inspections, rebuilds)

Example of Composite Heat Exchanger Weight Benefits (ref: P&W)



Potential Ceramic and CMC Components

Combustors

- Ramjet/scramjet flowpath
- Rocket engine
- Turbopump Preburners

Nozzles/Airframe Hot Structures

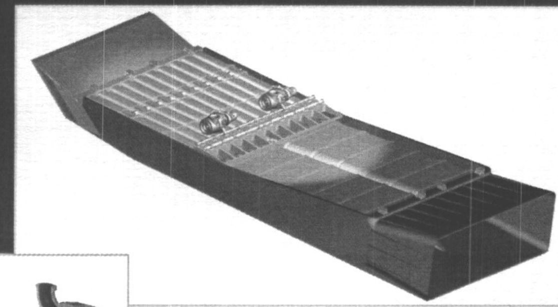
Turbomachinery Components

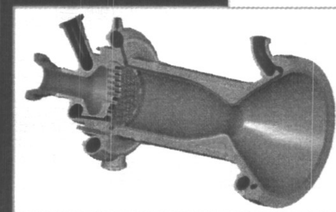
Leading Edges

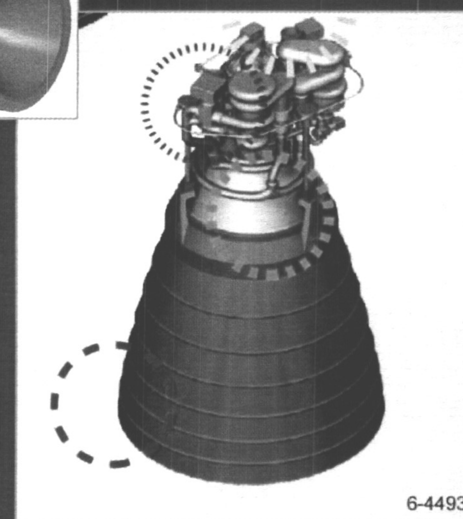
Hot Gas Ducting

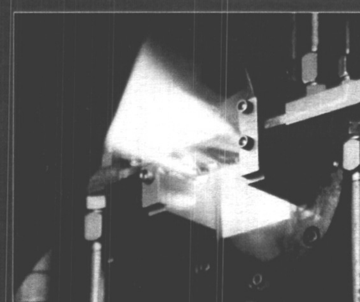
Bearings

Propellant Injectors



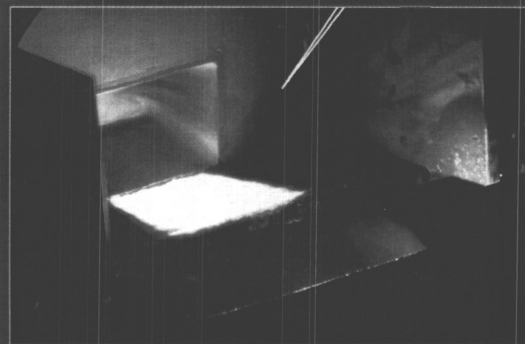


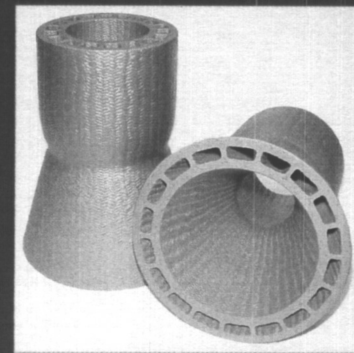




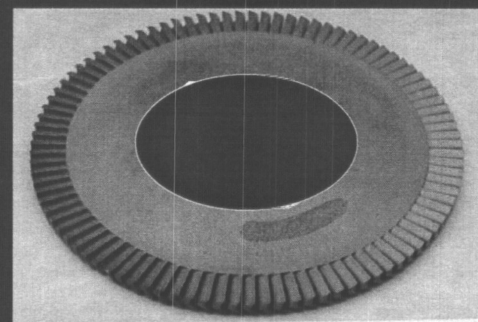
Component Needs Addressed by Three Focus Areas

- Actively Cooled Structures

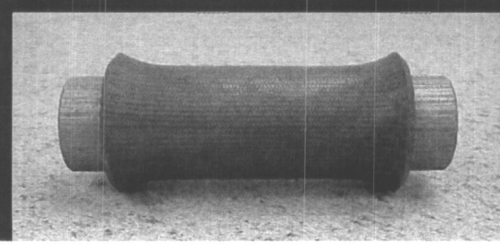


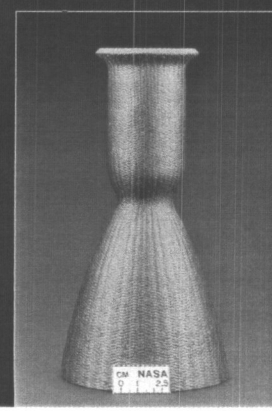


- Turbomachinery Components



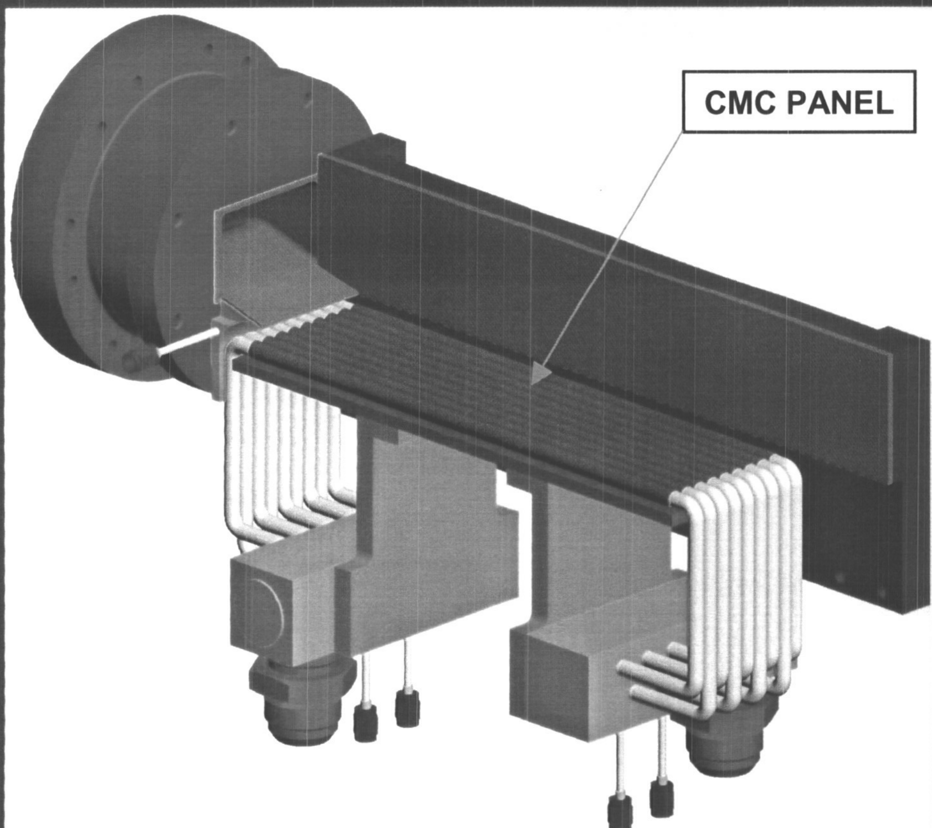
- Uncooled Thin-walled Structures





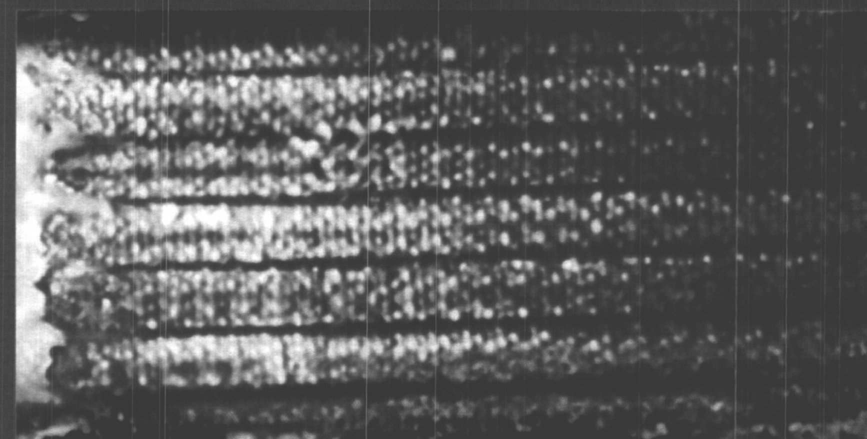
Cooled Composite Subelement Test at NASA GRC

Panel Arrangement at Thrust Cell Exit



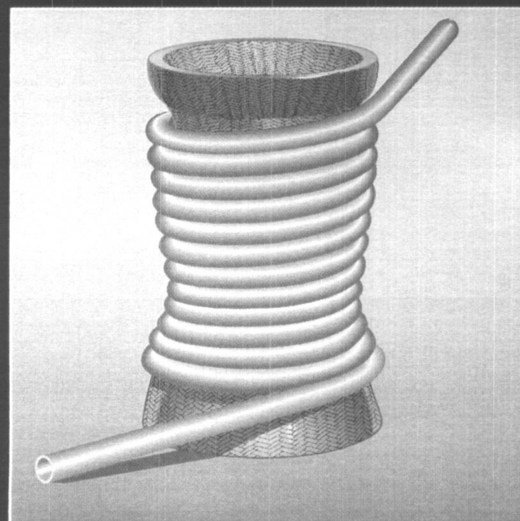
LEFT FENCE & ABLATIVE SHIELDING NOT SHOWN

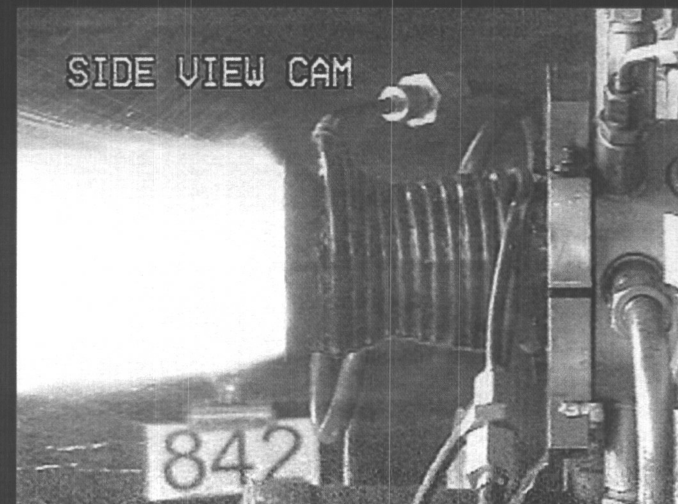
Top View During Test

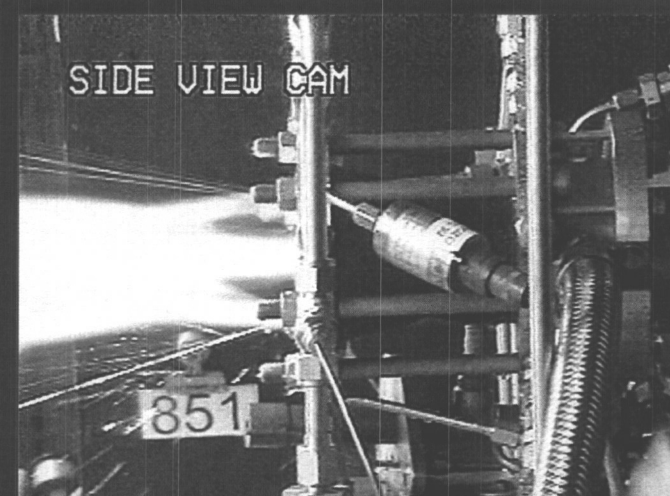


- Heat fluxes to 9 BTU/in^2-sec
- Outer surface temperatures to 2800 F

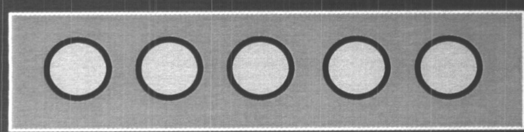
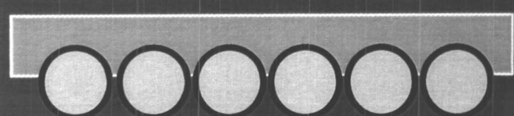
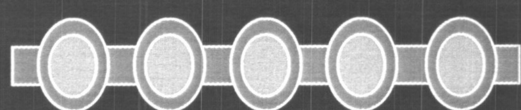
Cooled Composite Thruster Tests at NASA GRC





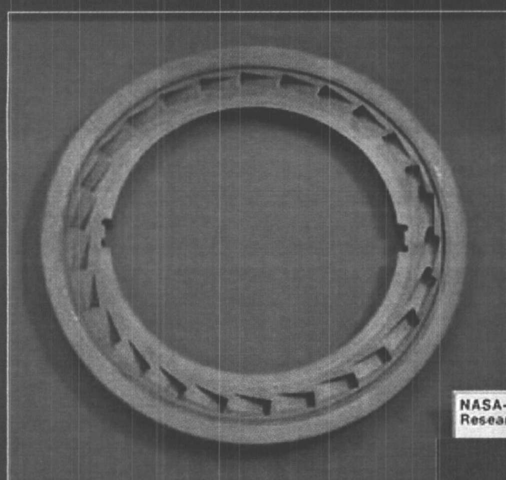


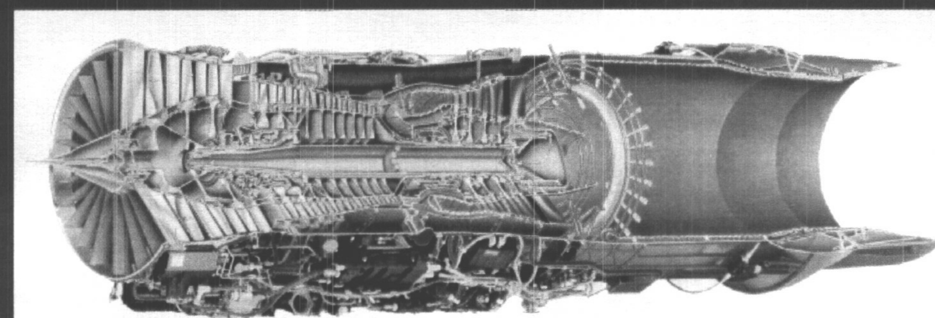
Actively Cooled Composite Configurations

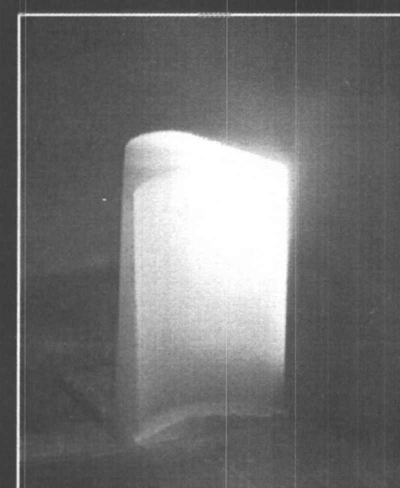
	"Interference fit" metallic tubes
	metallic tubes adhered (e.g.,brazed) to composite
	metallic tubes co-processed with composite
	Composite "tubed" structure

Turbomachinery Components

- **Turbopump and turbine engine blisks, stator/nozzles, inserted blades, etc.**



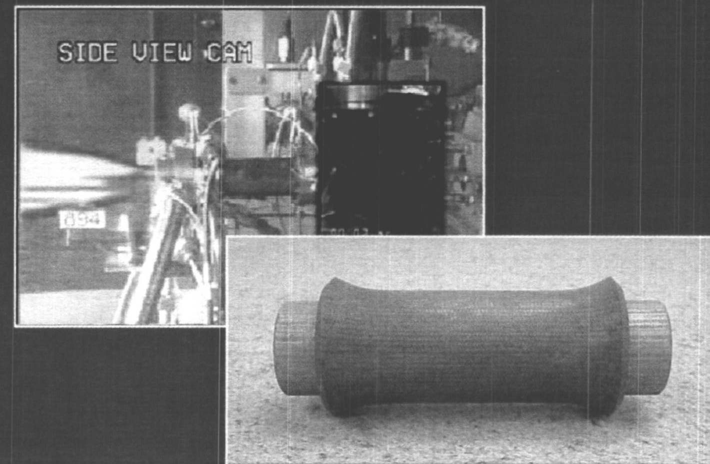




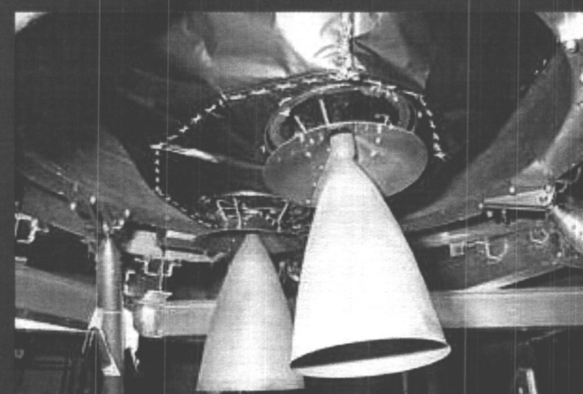
Uncooled Thin Walled Structures

<u>Targeted Components</u>

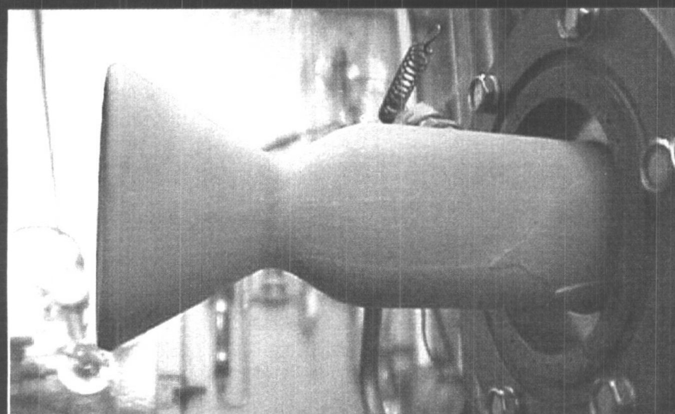
Turbopump Combustors
- Fuel-rich (H_2) combustion gases
- Temperatures ~2200F
- Currently actively cooled copper alloys

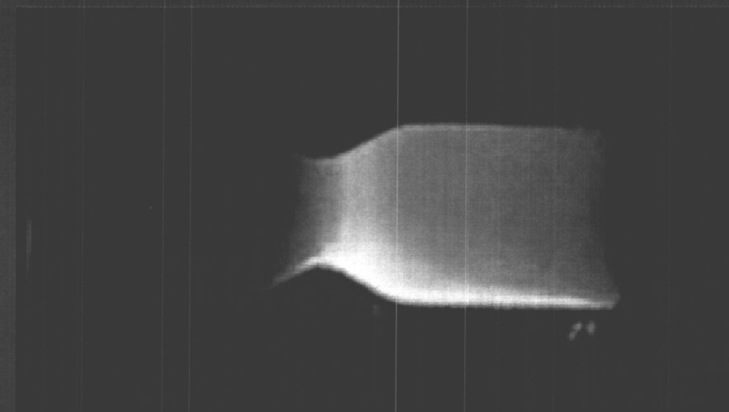


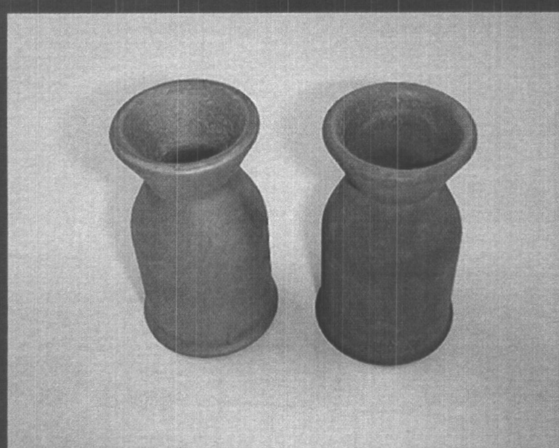
Satellite Insertion and Stationkeeping Thrusters
- Virtually all space missions
- Limiting for communication sats
- Enabling for planetary missions

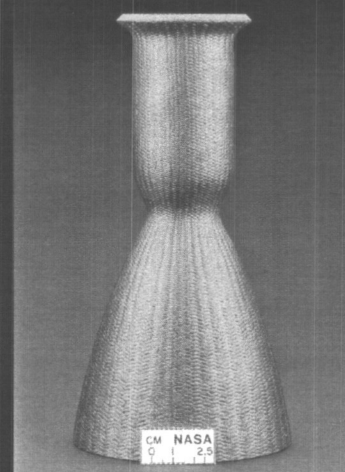


Uncooled Ceramic and CMC Thrusters









Requirements Drive Design Options

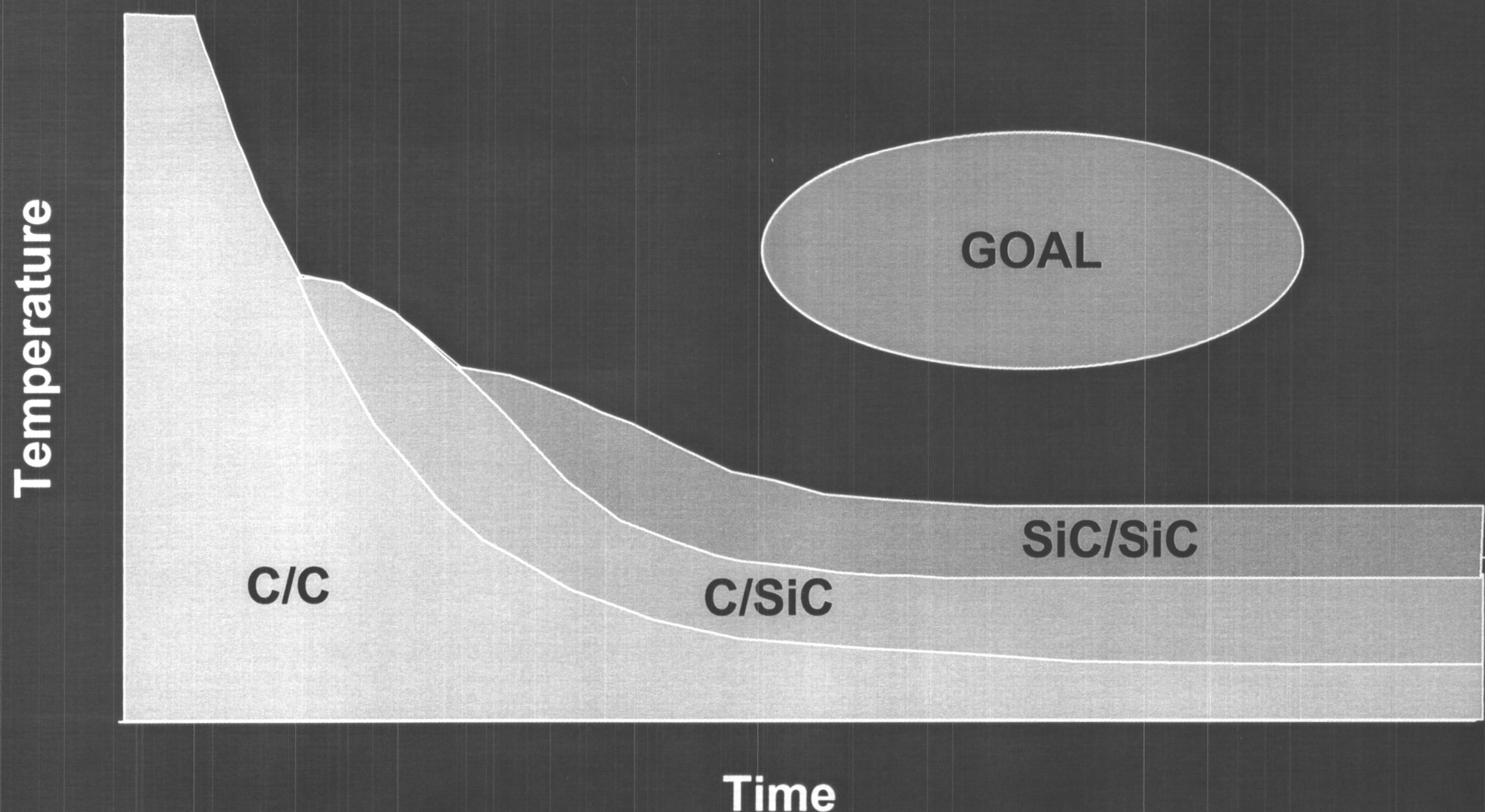
- Geometry
- Weight
- Coolant Type and State
- Heat Flux, Temperature
- Mission (cycles and duration)
- Acoustic Loads
- Aero-pressure Loads
- Maintainability/Repairability

Key Shortfalls/Challenges

- Composite durability (e.g., oxidation, fatigue)
- Proven full scale fabrication capabilities
- Reliable composite design properties
- Attachment/Joining methodologies
- Manifolding
- Backstructures
- Validated design codes
- Validated life codes
- Scaled manufacturing facilities/practices
- Inspection techniques

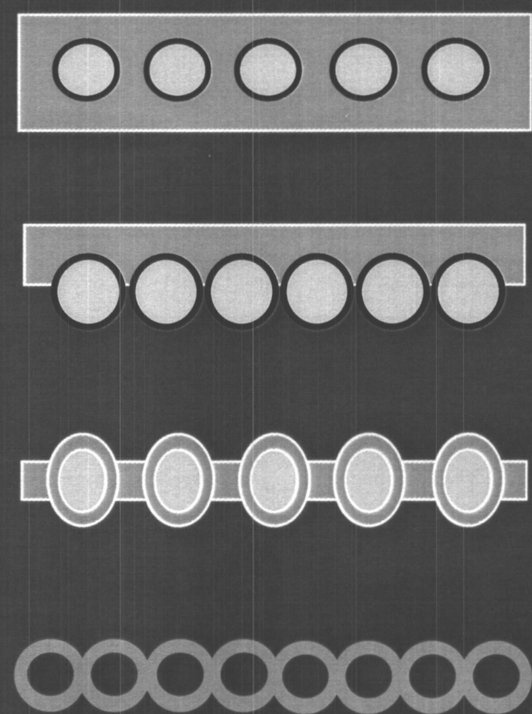
Composite Durability

No material system has shown required durability for 100's of reusable missions at temperatures above 1400 C.

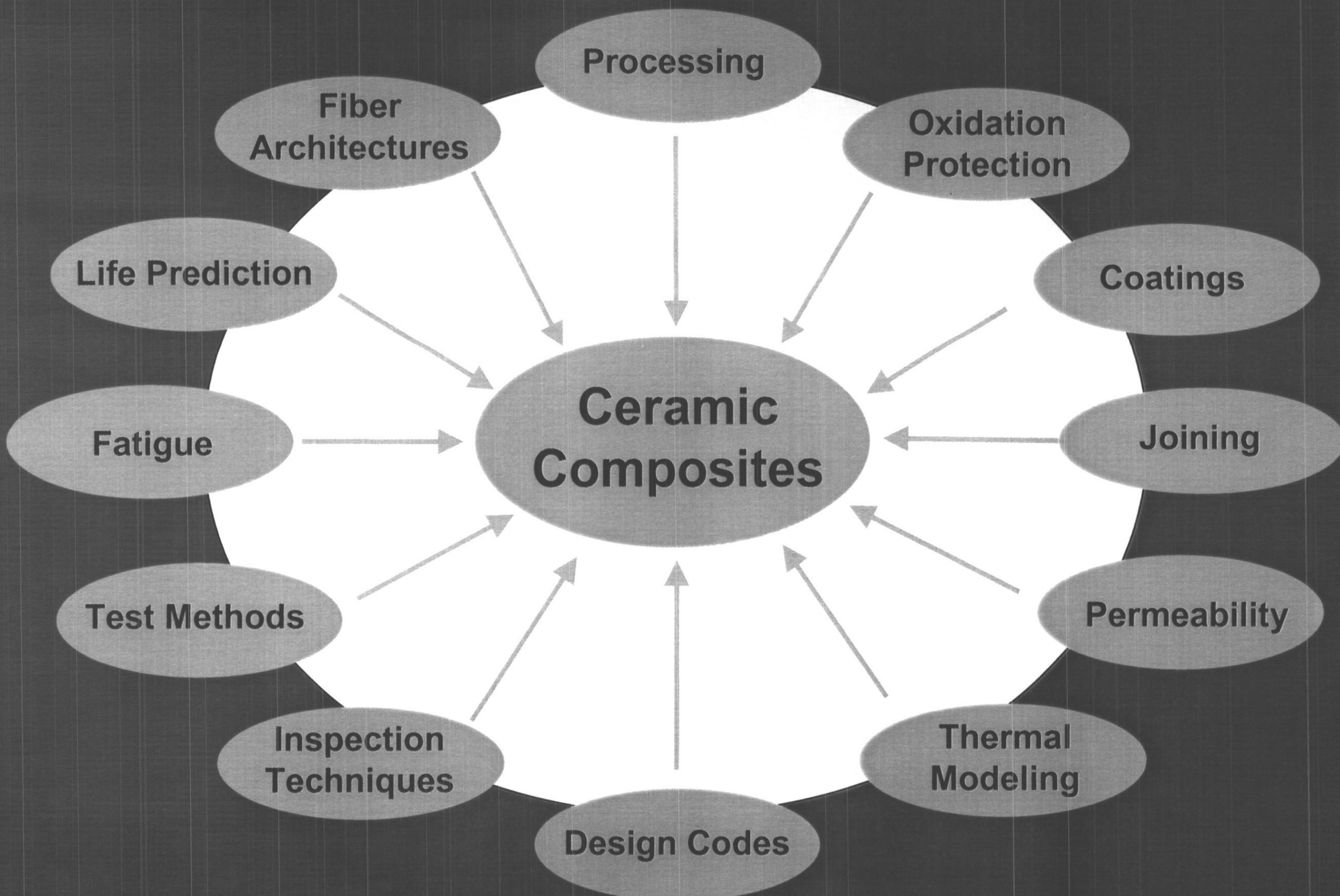


Attachments, Manifolding, Backside Structures

Generally design and application specific and oftentimes proprietary.



Understanding of Materials and Structures Base Technologies Required for Ceramic Composites



Summary

Ceramic materials are *key* to achieving the goal of low cost access to space (densities, thermal, and environmental capability).

NASA research efforts related to ceramic materials development is focused on three areas:

- actively cooled structures
- turbomachinery structures
- uncooled thin-walled components.

Ceramics and ceramic composites offer near term payoff for some specific space propulsion systems, but there remain key technology shortfalls to overcome prior to widespread application of these materials in reusable space propulsion systems.

THE ROLE OF CERAMICS AND CERAMIC MATRIX COMPOSITES IN NASA'S ADVANCED SPACE PROPULSION PROGRAMS, Andrew J. Eckel, NASA Glenn Research Center, Cleveland, OH 44135

In recent years, NASA has embarked on several new and exciting efforts in the exploration and use of space. The successful accomplishment of many planned missions and projects is dependent upon the development and deployment of previously unproven propulsion systems. Key to many of the propulsion systems is the use of structural ceramics and ceramic matrix composites.

In spite of their promise, a number of programmatic and technical hurdles remain before the potential of ceramic materials can be realized. A programmatic environment which focuses on relatively short term hardware demonstration programs precludes traditional longer term material's development efforts. The challenge oftentimes becomes one of engineering ceramics into proposed missions. This is dependent upon a fundamental understanding of processing, degradation and design issues unique to space vehicle design and operations.

A review of the general missions and benefits of utilizing ceramics and ceramic matrix composites will be presented. The design parameters and operating conditions will be presented for both specific missions/vehicles and classes of components. Key technical challenges and opportunities are identified along with suggested paths for addressing them.